Instability in Distributed Mobility Management

- Revisiting Configuration Management in 3G/4G Mobile Networks

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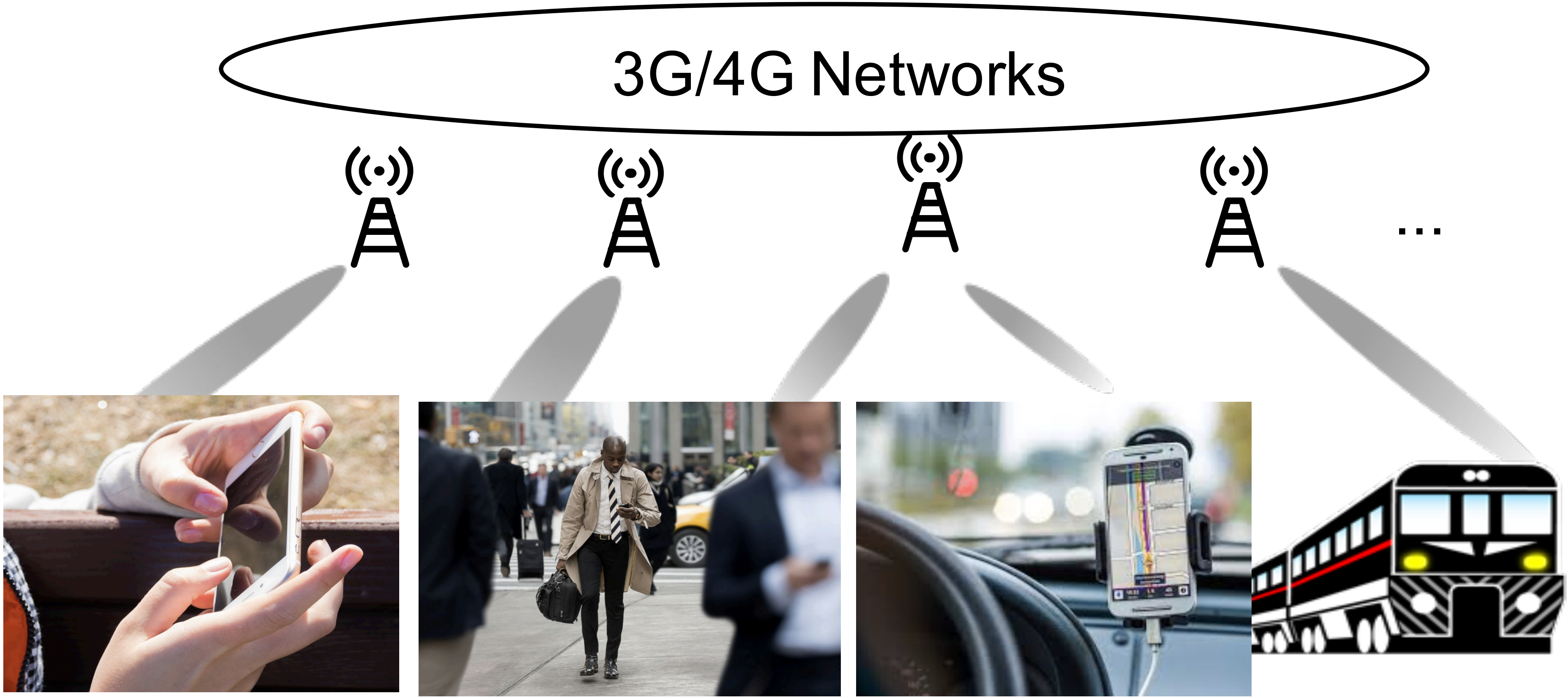
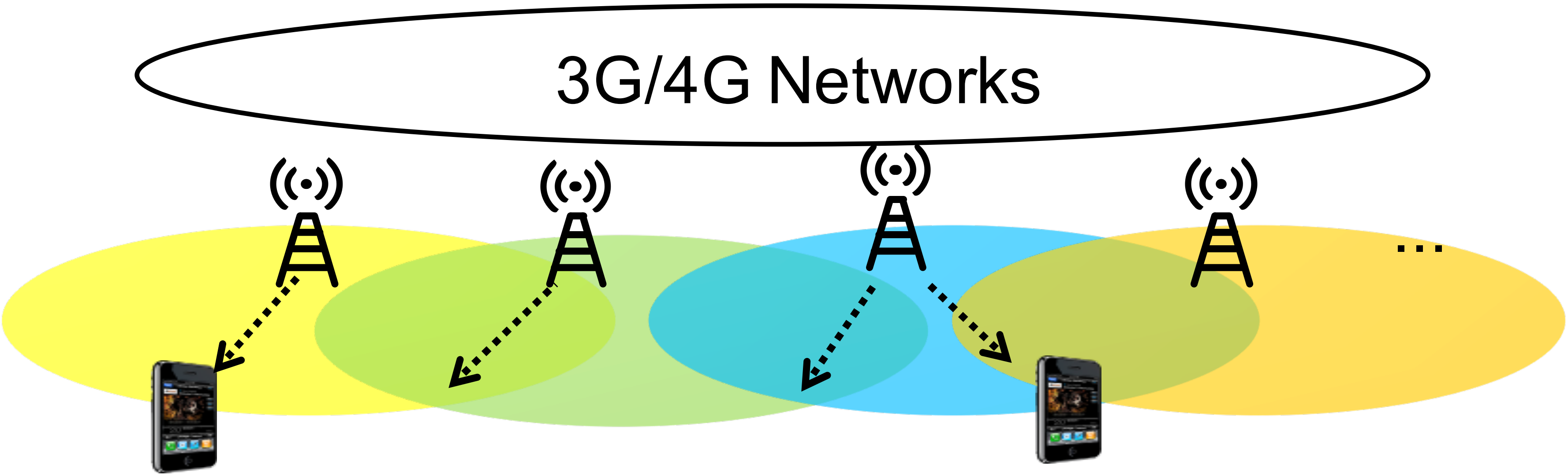
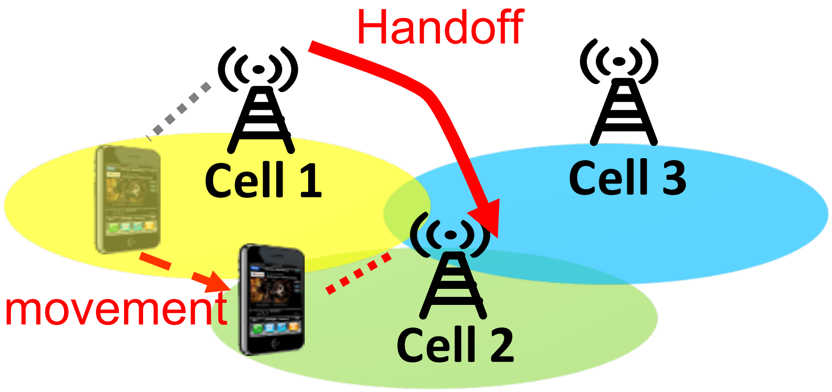
"Anytime, Anywhere" Access via Cellular Networks

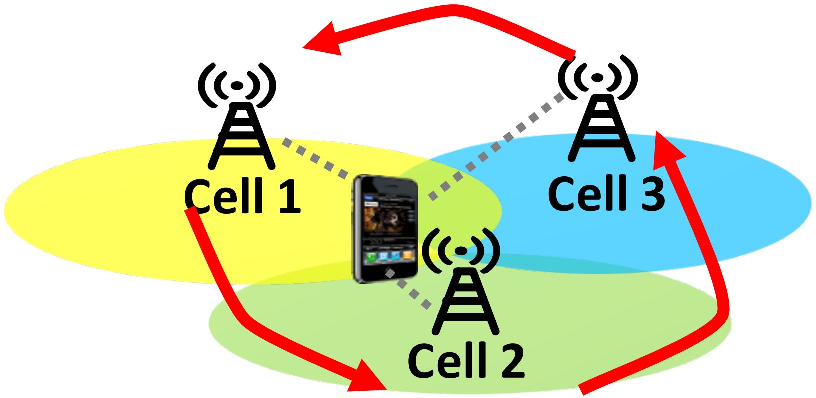


Mobility Management (MM) Via Handoff



Handoff Stability

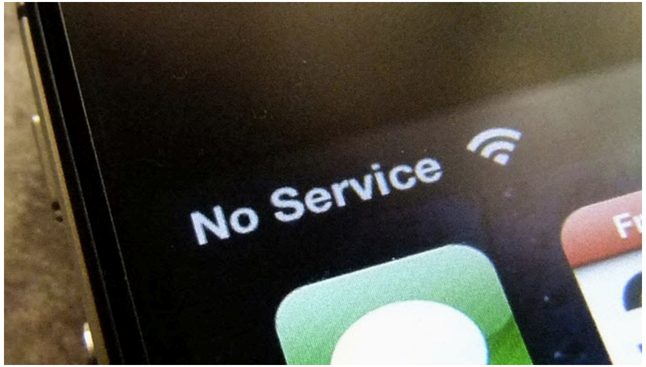




- Stability
  - Converge given invariant settings (location, radio quality, traffic, etc.)
- Instability
  - No convergence
  - persistent loop: C1->C2->C3->C1->C2->C3…

Why Stability Desirable?

- Handoff comes at a cost
  - 100ms ~ 10s for each handoff
  - Radio/network resource consumed (e.g., 3-8x signaling msgs)
  - Service degradation/disruption (e.g., 10-20x slowdown)
- Frequent handoffs -> much more pain



Clarification

- Instability ≠ Transient loops
  - Not ping-pong effects caused by radio dynamics & user movement

- Our focus: Persistent loop
  - Caused by fundamental (persistent) conflicts (e.g., misconfigurations, inconsistent policy, logic conflicts)
  - Structural property in mobility management

This Work

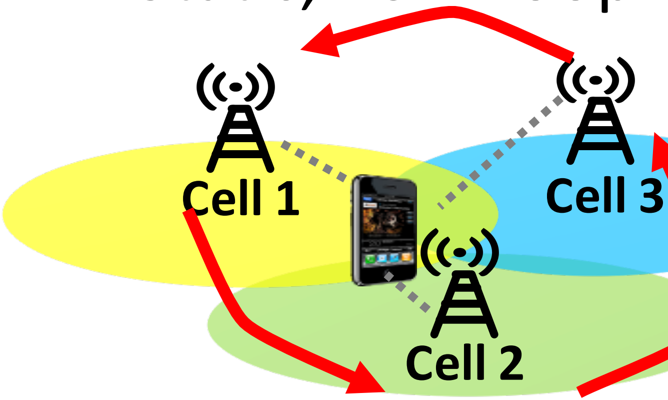
- Q1: Does unstable handoff exist in reality?
- Q2: When (under what conditions) shall instability happen?
- Q3: How to detect instability?

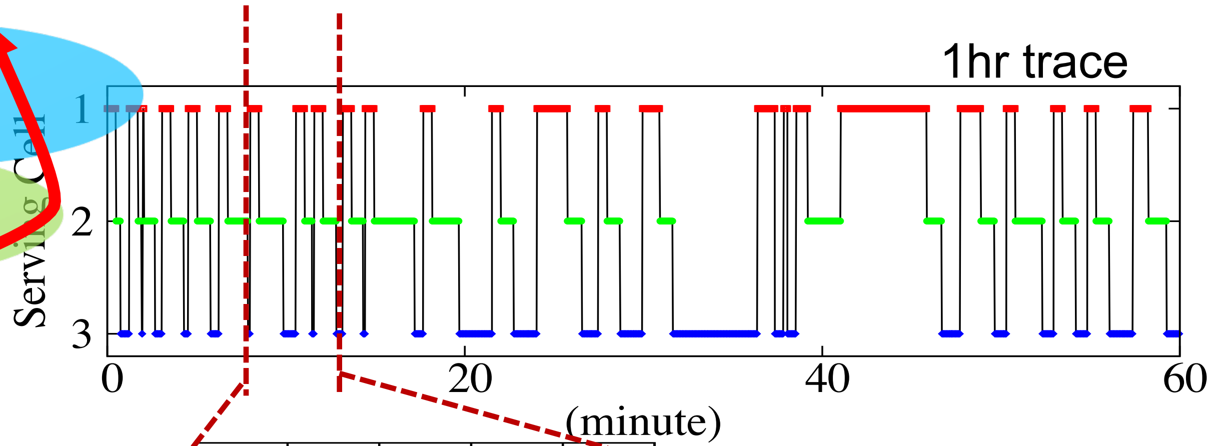
Q1: Does instability exist?

Unfortunately yes!

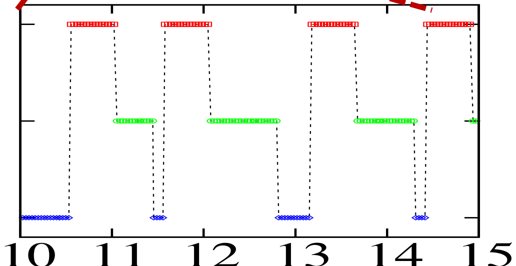
3-Cell Loop Example

- Static, 40hr-loop





Cell1: 4G
Cell2: Femtocell (3G)
Cell3: 3G

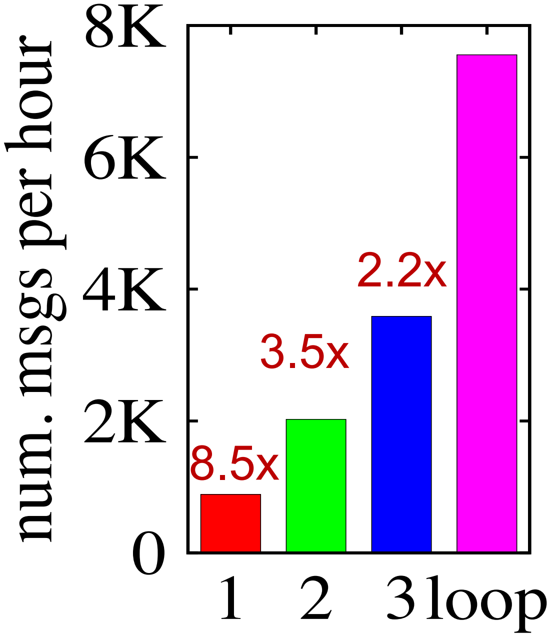


Loop every few mins
(90% loops in 200s)

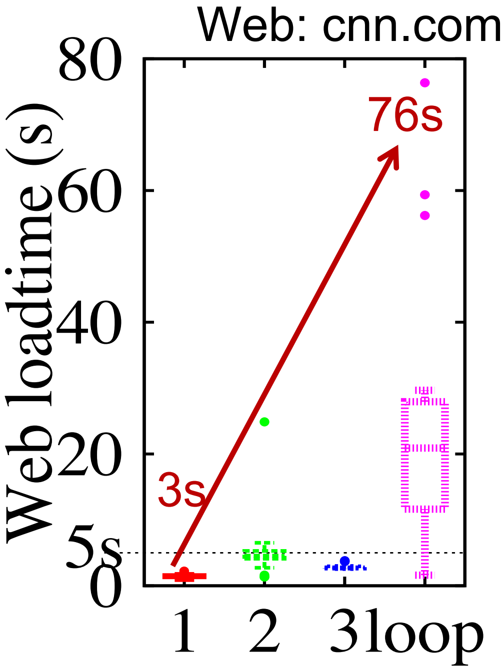
Negative Impacts Verified in Real-world

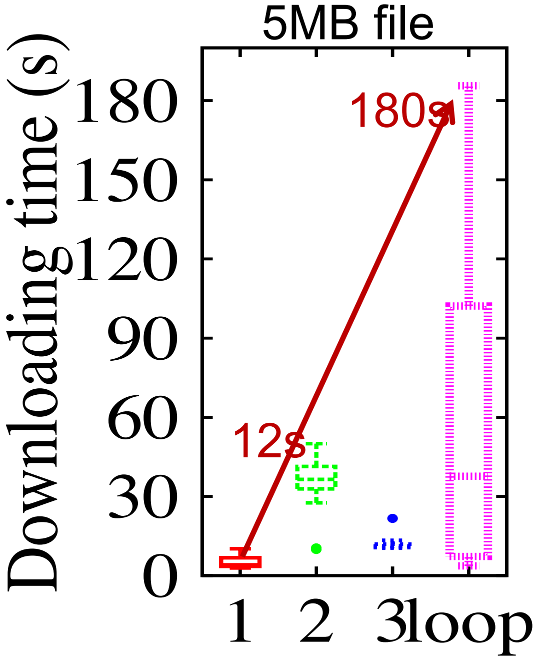
Harm to both carriers and users

- Excessive signaling overhead



- Performance degradation



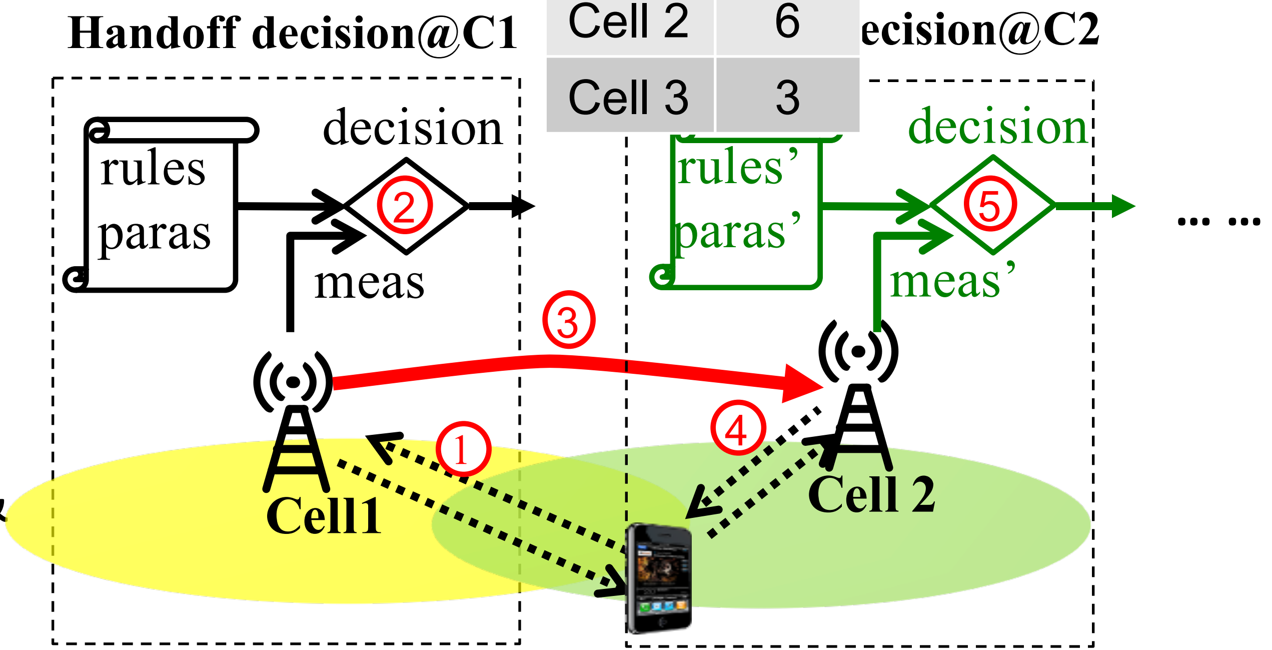


How Can It Happen?

- Handoff: Trigger-decision-executio

Cell	Pref
Cell 1	4
Cell 2	6
Cell 3	3

- Configurable
  - Tunable para & decision logic
- Distributed
  - Local decision & configurations

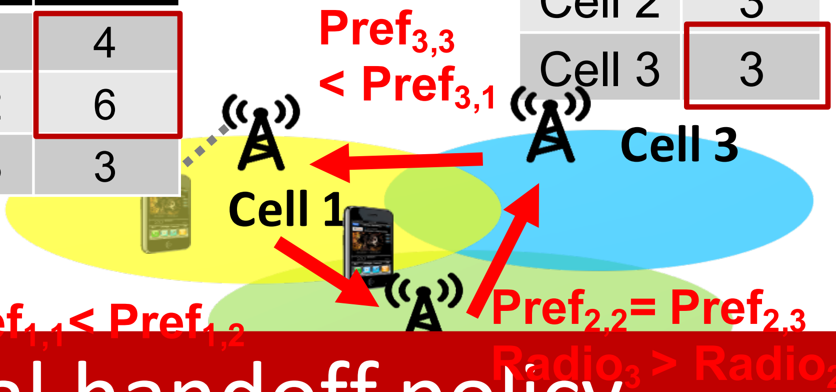


Loop Caused Inconsistent Configurations

- Different preferences driven by diverse needs
  - C1→C2 (4G→Femtocell): traffic offloading
  - C2→C3 (Femtocell→3G): Equal preference, better radio
  - C3→C1 (3G→4G):

Cell	Pref
Cell 1	4
Cell 2	6
Cell 3	3

Cell	Pref
Cell 1	5
Cell 2	3
Cell 3	3



Well-justified individual handoff policy

≠

Well-behaved handoff among cells

Q2: When shall instability happen?

Formulation and analysis (Details in the paper)

Formulation

- **Each handoff decision**: $s \rightarrow [t = F_s(C,P)]$
  - *s*, *t*: serving/target cell
  - F_s: decision logic (function) for serving cell s
  - *C*: set of candidate cells (with runtime meas)
  - *P*: configurable parameters

- **Handoff sequences**: $s \rightarrow c_1 \rightarrow \ldots \rightarrow c_i \rightarrow [c_{i+1} = F_{ci}(c_i)] \rightarrow \ldots \rightarrow t$

- **Stability**: for any ***invariant*** measurements, any handoff sequence always converge to a single cell t

$s \rightarrow [t = F_s(C,P)]$?

- Idle-state handoff (w/o traffic)
- Active-state handoff (w/ traffic)

Idle-State Handoff

- Easy!
- Regulated by 3GPP standards
- Based on radio evaluation

@s, pairwise comparsion

$c \in C$, c wins if one is satisfied

$$\begin{cases} P_{s,c} > P_{s,s}, & r_c > \Theta_{s,c}^{high} \\ P_{s,c} = P_{s,s} & r_c > r_s + \Theta_{s,c}^{equal} \\ P_{s,c} < P_{s,s} & r_s < \Theta_s^{serve}, r_c > \Theta_{s,c}^{low} \end{cases}$$

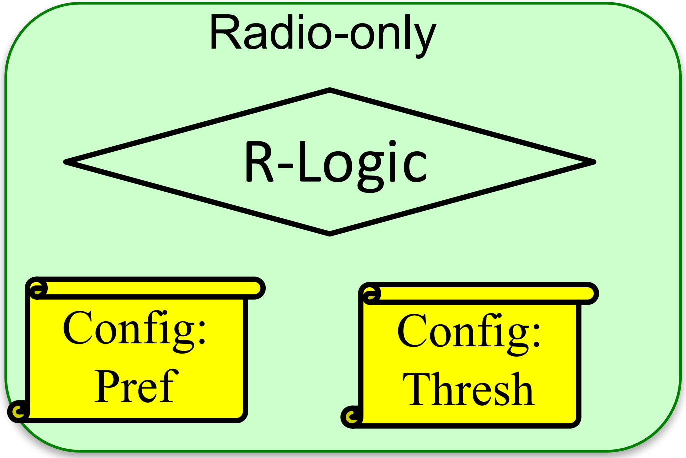
preference

radio evaluation (threshold)

Idle-State Handoff

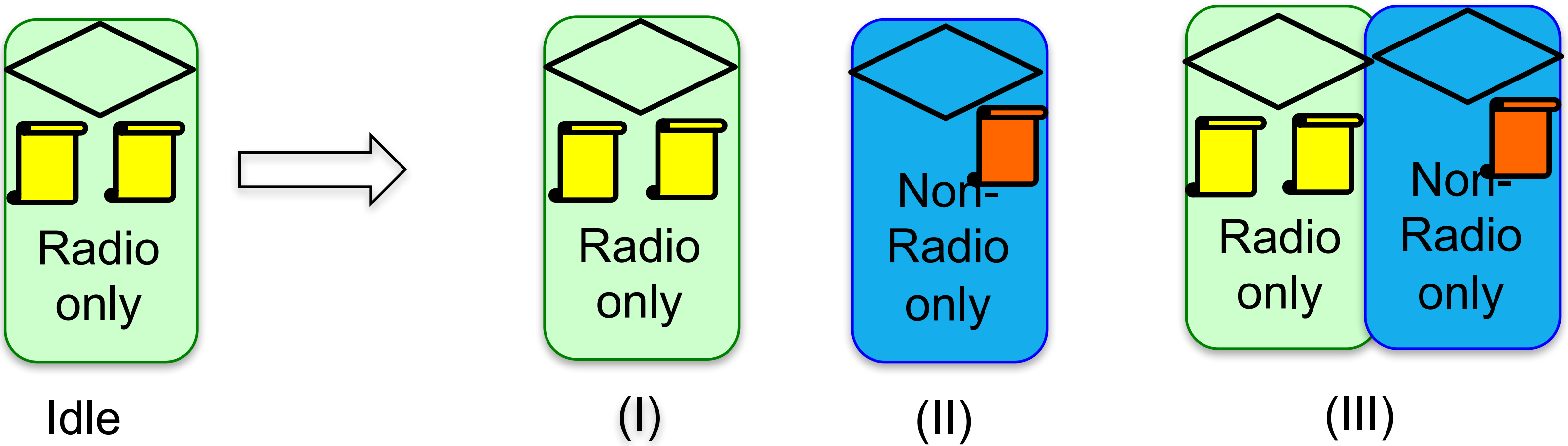
- *Radio-only handoff*
- F_s: known (same at cells)
- *P*: configurable parameters (preferences & thresholds)

$s \rightarrow [t = F_s(C,P)]$

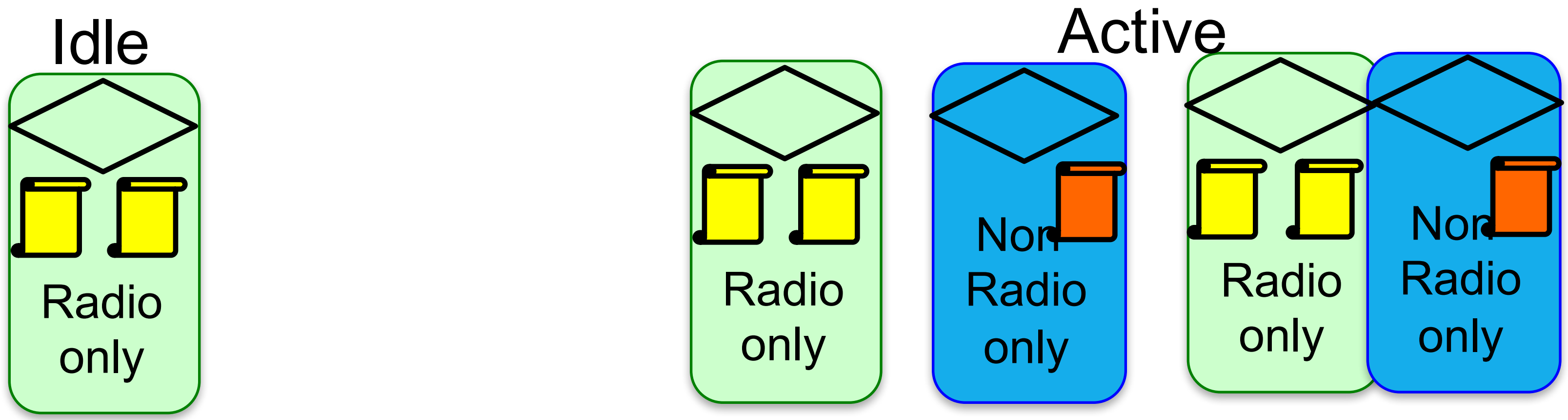


Active-State Handoff

- Not easy!
- Not fully regulated (e.g, Vendor-specific polices)
- Based on radio and/or non-radio evaluation



Causes of Instabilities: A Classification



- Uncoordinated configurations
  - Inconsistent preferences
  - Inconsistent thresholds
  - Active-idle misconfigurations
- Loop-prone decision logics
  - Active-active logic conflicts
  - Active-idle logic conflicts

Instability Conditions

- Inconsistent preferences (loop in preference settings)

Proposition-1

A persistent loop $c_1 \rightarrow \ldots \rightarrow c_n \rightarrow c_1$ can **always** happen under some invariant measurements, if

1. At least one cell c_i configures $Pref_{i,i} < Pref_{i,i+1}$
2. Every cell c_j configures $Pref_{j,j} <= Pref_{j,j+1}$, $Pref_{n,n} <= Pref_{n,1}$

Other Instability Conditions

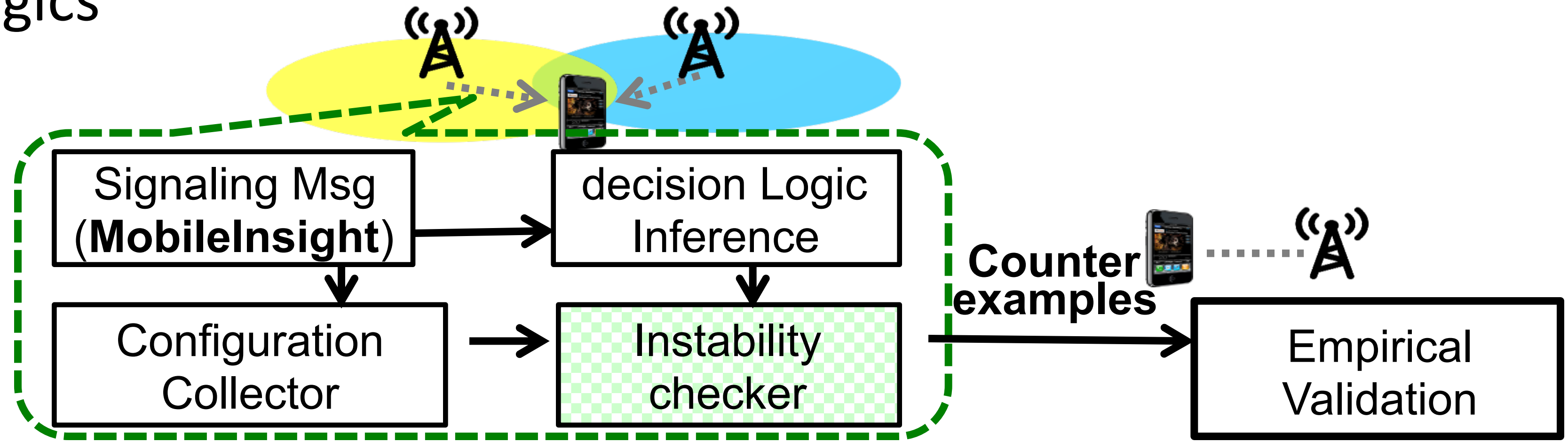
- Inconsistent radio thresholds (**Prop-2**)
  - In fact, preferences + thresholds
- Active-Idle misconfiguration (**Prop-4**)
  - Similar to Prop-2, but radio conditions are necessary but not sufficient for active handoffs
- Active-active logic conflicts (**Prop-5**)
  - When radio evaluation is involved
- Active-Idle logic conflicts (**Prop-6**)
  - Loop-prone in case the active handoff does not evaluate radio conditions

Q3: How to Detect Instabilities?

Detection and real-world check

In-Device Detection

- **Approach**: given configuration parameters/logics, check (in)stability conditions
- No data from operators!
- **In-device**: infer network-side configurations and decision logics



http://metro.cs.ucla.edu/mobile_insight/

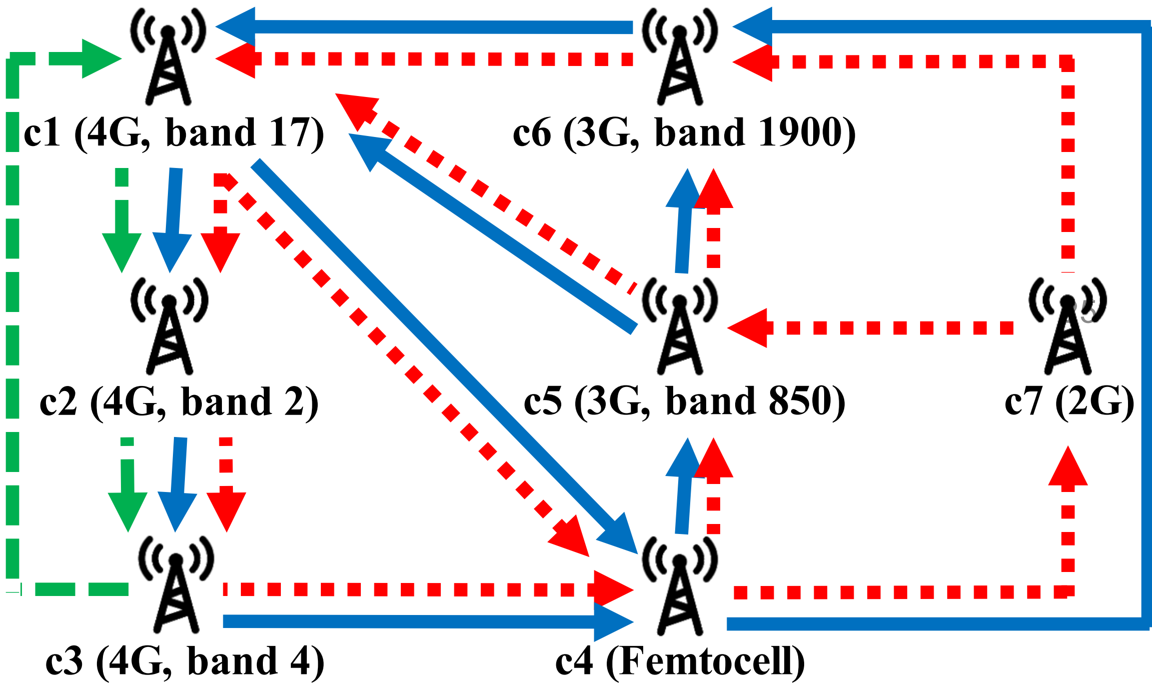
Experiment Settings

- Two major U.S. mobile network operators
- In two US cities (Los Angeles, CA and Columbus, OH)
- 50 outdoor locations, 63 indoor locations,

- 21 instances of instabilities detected and observed in reality, covering all the categories

Inconsistent Preferences

- 17 instances found in one U.S. operator
- Diverse causes in reality
  - L1: 4G-Femtocell-3G: uncoordinated goals
  - L2: 4G-Femtocell-2G-3G: device-side misconfiguration
  - L3: 4G-4G: imprudent 4G infrastructure upgrade

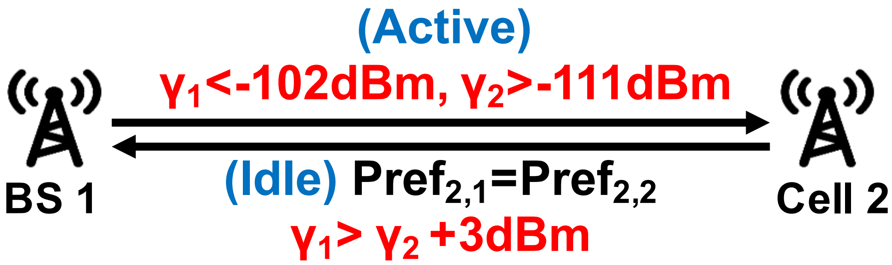


Inconsistent Thresholds

- None

Active-Idle Misconfiguration

- L4: 3G-Femto

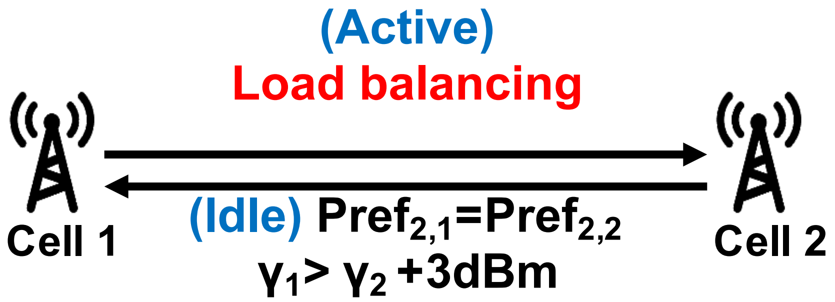


- 1 instance found in both U.S. operators
- A design loophole in 3G Radio Resource Control (RRC) protocol
  - Active-state handoff: thresholds of radio quality conflict with idle-state handoff decision logic

Active-Active and Active-Idle Logic Conflicts

- Active-Active logic conflicts
  - L5: 4G-4G
  - 1 instance in one US operator

- Active-Idle logic conflicts
  - L6: 3G-3G (both operators)
  - L7: 3G-Femto (one operator)



How Common?

	#Scenario instances	Occurrence of Misconfigurations or Loop-prone logic	Loop occurrence (parameter+logic +observation)
L1: 4G-Femto-3G	8	96.8%	25.0%
L2: 4G-Femto-2G-3G	8	96.8%	0.49%
L3: 4G-4G	1	2.2%	2.2%
L4: 3G-Femto	1	96.8%	9.4%
L5: 4G-4G	1	1.6%	1.6%
L6: 3G-3G	1	63.4%	2.15%
L7: 3G-Femto	1	96.8%	0.49%

Discussion: Fix Guidelines

- Network-side solution
  - Self-check of configuration conflicts
  - Safe configuration update (loop-free)
  - Handle policy update (dynamics)
  - Runtime migration (history information)

- Device-side solution
  - In-device detection
  - Break the loop (requires access to phone chipset)

Conclusion

- Instability exists in mobility management plane
  - Distributed management in nature
- Instability can be prevented with coordination of mobility management
  - Regulation of parameters and decision logics are necessary
- More research aspects remain open
  - Other structural properties: reachability, optimality, convergence speed, etc.

Thank you!

http://web.cse.ohio-state.edu/~chunyi/projects/mmdiag.html

MobileInsight (tool): http://metro.cs.ucla.edu/mobile_insight/